



Spatial distribution of physicochemical-bacteriological parametric quality and water quality index of Gomti River, India

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Abstract Surface water bodies are vital source of water for human consumption, domestic needs, agriculture, industrial activities, and also for aquatic life and ecosystems. In this study, a stretch of river Gomti was studied at 5 sites in Lucknow for two consecutive seasons during 2019. The physicochemical-bacteriological parameters of water and sediment samples were analyzed, followed by multivariate statistics. Mean values of pH, turbidity, EC, TS, TDS, TSS, DO, BOD, COD, nitrate, phosphate, sulfate, total alkalinity, total hardness, chloride, and fluoride during the pre-monsoon period were 7.4 ± 0.2 , 5.2 ± 3.3 (NTU), 444.4 ± 97.4 ($\mu\text{S}/\text{cm}$), 274.6 ± 61.6 , 254.3 ± 50.2 , 21.9 ± 11 , 5.4 ± 1.6 , 10.2 ± 5.9 , 31.2 ± 13.3 , 1.2 ± 0.5 , 1.7 ± 1.1 , 25.9 ± 3.7 , 204 ± 41.8 , 146.2 ± 11.5 , 15.5 ± 8.7 , and 0.5 ± 0.1 mg/l, respectively. The corresponding values during the post-monsoon season were 7.5 ± 0.2 , 5.5 ± 3.2

(NTU), 436 ± 75.1 ($\mu\text{S}/\text{cm}$), 273.7 ± 124.2 , 209.7 ± 82.5 , 63.9 ± 43.4 , 5.6 ± 1.6 , 15.8 ± 8.9 , 39.2 ± 23.5 , 5.4 ± 4.6 , 1.4 ± 0.9 , 25.5 ± 5 , 199.2 ± 36.6 , 134 ± 8.6 , 20.2 ± 8.9 , and 1.7 ± 0.2 mg/l, respectively. Concentration of pollutants significantly increased by 5–15% from sampling station S1 (upstream) to S5 (downstream). Enumerations of fecal coliform and *Escherichia coli* bacteria were low at S1 but significantly higher at the S5 site. WQI ranged from 88 to 345 during pre-monsoon and 159 to 422 during post-monsoon period, indicating poor water quality which was unsuitable for drinking purposes. Strong positive correlations (≥ 0.9) were observed among pH, chloride, phosphate, sulfate, turbidity, conductivity, TS, TDS, BOD, and COD for water samples during both seasons. The data reveals that pollution load increases gradually from upstream to downstream due to the increasing discharge of raw sewage. Regulatory bodies should formulate strict regulations and ensure their implementation for the protection and management of river water quality.

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Introduction

Rivers are the main source of surface water for domestic (bathing, washing, recreation), agriculture, pisciculture, and industrial activities. The majority of the Indian rivers are rain-fed and they become the source

of drinking water. Indian cities are densely populated and discharge huge amounts of untreated municipal sewage into rivers due to a lack of adequate wastewater treatment facilities (Godha et al., 2018; Balha & Singh, 2018). The increasing discharge of sewage and wastewater not only pollutes the river water, it also reduces the assimilative capacity and self-purification system of the river thus resulting in the diminishing of drinking water availability (Chakravarty & Gupta, 2021; Kumar, 2018). Statistical evidence reveals increased water-borne diseases and mortality in the world due to the consumption of contaminated water (WHO, 2021). Different anthropogenic activities have induced the disposal of sewage, agricultural residues, industrial contaminants, and other unwanted chemicals into rivers (Chen et al., 2020; Kumar et al., 2020; Pant et al., 2018). Surface run-offs carry contaminated sewage mixed with heavy metals, pesticides, pathogens, sulfate, phosphate, nitrates, fluoride, and a variety of toxic chemical contaminants into the rivers (Jiang et al., 2020; Matta et al., 2020).

The Gomti River is one such Indian river that routinely carries domestic sewage, industrial wastewater, agriculture, and other pollutants released from point and non-point sources over a river basin (Kumar et al., 2020; Singh et al., 2005). Traditional religious practices such as idol immersion during festivals, disposal of pathogenic biomedical/fecal wastes, surfactants, color discharge from local chikan factories, oil and grease from vehicular workshops, and agricultural run-off from farm fields have a cumulative adverse impact on water quality and pose a serious threat to flora and fauna of the river system (Chakravarty & Gupta, 2021; Tiwari & Kisku, 2016).

Regular monitoring is required for spatial, temporal, and parametric comparisons of the river water to regulate, maintain, and preserve water resources (Jiang et al., 2020; Shukla et al., 2017). For this purpose, the water quality index (WQI), which is a digital index for grading of water quality based on its key parameters for qualitative analysis was analyzed (Matta et al., 2020; Tripathi et al., 2011; Tian et al., 2019; Shil et al., 2019). Any single water parameter does not reflect the overall water quality of the river, hence WQI is used to measure the enormity of contamination by researchers and policymakers (Ejoh et al., 2018; Wang et al., 2017). Horton (1965) proposed a statistical tool for the water quality index (Horton, 1965). Since then, different indices have been developed and used for

evaluating the WQI before water supply to consumers and control of water pollution. After comprehensive analysis, different key parameters are integrated to generate a unit less digital value of WQI. Based on WQI, water is grouped into 5 classes, viz., very good, good, poor, very poor and worse (unsuitable for drinking purposes). Water quality of different sources/regions can easily be compared by comparing the values of WQI, instead of cumbersome computing/comparing the numerical data of various water quality parameters (Nayak et al., 2020).

The magnitude of the contamination was impartially studied by evaluating the physicochemical parameters of water samples from a limited river flow portion of Gomti River. However, the composite analyses of physicochemical/biological/bacteriological parameters for both water and sediments samples of the river, and also a significant association between the seasonal variation of the river water quality are rarely studied (Mishra et al., 2017; Parveen & Singh, 2016; Dhananjay et al., 2013). Besides, earlier research works have recommended multivariate statistical analysis methods for estimation of the most probable sources which impact the river water quality (Malik et al., 2011; Shivani et al., 2011; Singh et al., 2005). Identifying the sources of contamination in the Gomti River is essential. Moreover, due to over-exploitation of groundwater, the combined recharge from Gomti River and rainfall has gone down more than 17 times in Lucknow. With this rationale, the current study aimed to delineate the following four objectives: (i) to assess the water quality and bed sediment of the Gomti River during pre-monsoon and post-monsoon seasons, (ii) to determine correlations among the physicochemical-bacteriological parameters of water and bed-sediment samples, (iii) to calculate WQI for the sampling locations, and (iv) to estimate the magnitude of variation among parameters as well as sampling locations over the course of the river using multivariate statistical methods to classify the dominant sources that affect the Gomti River water quality.

Materials and methods

Study region

The area under study of Lucknow City lies between the geographical coordinates of 26° 51' N and 80° 55' E. The Gomti River originates from the Gomati Taal (Fullhar Jheel) in the Terai region (foothills) of the Great

Himalayas in Pilibheet, India. It traverses ~240 km before entering Lucknow and divides the city into *cis*-Gomti (right bank) and *trans*-Gomti (left bank). The study area stretches for ~30 km through Lucknow City, starting from Ghaila Bridge at IIM road and extending up to Shaheed Path, points which are considered as the entry and exit points of the river in the city, respectively. Gomti River water is the main source for drinking, agriculture, and pisciculture in Lucknow City, the capital of Uttar Pradesh Province with a population of 2.81 million (Census of India, 2011). The geo-referenced mapping for the study region and 5 selected sampling points (S1: Ghaila Bridge, S2: Gau Ghat, S3: Kudiya Ghat, S4: Gomti Barrage, S5: Shaheed Path) are illustrated in Fig. 1. M/s. Hindustan Aeronautics Ltd. (HAL), Tata Motors, Railway Carriage and Wagon Shop (C&W), battery industry, many small/medium scale industries, bakeries, vehicle workshops, dairy farms, vegetable waste, oil and grease, surfactants used for cloth washing at river site, biomedical/animal waste, fish/meat markets, cattle sheds are some of the major contaminating sources and industrial activities around the river banks which have a significant contribution to the Gomti River pollution (Kumar et al., 2020; Malik et al., 2011; Singh et al., 2005). As the population increased the built-up area of Lucknow City also expanded 43.8% between 1993 and 2019 (Sarif & Gupta, 2020) which has further impacted the river water quality. Newly constructed buildings and infrastructure expansion have also impacted the water quality.

Sample collection and physicochemical-bacteriological analysis

Sample collection was carried out in the months of April and November 2019 which covered the pre-monsoon and post-monsoon seasons. Standard protocols were followed during collection, preservation, and analysis of the samples (APHA, 2017; BIS: 10500, 2012). Grab water samples were collected in Teflon bottles from both banks and middle of the river using a water sampler with the help of a boat. Sterilized 100-ml-cell culture bottles were used for bacterial sample collection. Water and bacteriological samples were taken to the research laboratory in an icebox (4 °C). Sixteen physicochemical parameters and biological examinations were carried out for pre-monsoon and post-monsoon samples of water and

sediments to assess the variance in parametric quality of Gomti River.

Water samples were fixed for dissolved oxygen (DO) at the site itself by adding 2-ml-alkaline iodide azide and 2-ml-manganese sulfate while pH and electric conductivity were measured by the ion-selective electrode (LAQUA F-74BW-G, Horiba, Ltd. Japan). The gravimetric method was used for total dissolved solids (TDS), total suspended solids (TSS), and total solids (TS). Turbidity by turbidity meter, total hardness (Ca^{++} and Mg^{++}) by EDTA titrimetric, chloride by argentometric titration, total alkalinity by sulfuric acid titration, DO by Winkler's method, and biochemical oxygen demand (BOD_5) by azide (Winkler's) modification method for 5 days at 20 °C, while the open reflux digestion method for chemical oxygen demand (COD) was used during sample analysis. Phosphate, nitrate, sulfate, and fluoride were estimated by ion chromatography (Metrohm-940 Professional IC Vario1, Germany). The MPN method was used for the enumeration of indicator organisms, viz., total coliform and fecal coliform in river water. Culture media for bacteriological analysis were procured from Hi-Media Pvt. Ltd., Bombay, India.

Fourier transform infrared spectroscopy (FTIR) for bed-sediment analysis

Functional groups of the sediment samples have been identified through FTIR coupled with ATR (attenuated total reflectance), (Model Nicolet™ iSTM5 Thermo Fisher Scientific, USA) which has a spectral range from 4000 to 500 cm^{-1} with 16 scans and a resolution of 4 cm^{-1} . FTIR is a modern analytical instrument and is typically used for detecting functional groups based on identified chemical bonds of solid samples by the infrared absorption spectrum principle. The properties of the upper layer of river bed sediment of Gomti were studied to estimate the degree of water contamination. An attempt was also made to assess potential and continual sources of pollutants with correlation characteristics of water during the summer season when the temperature of surface water increases. The characteristics of sunk sediment material in Gomti River water were used to assess the potential correlation with characteristics of water and estimate the most probable contaminating sources of Gomti River.

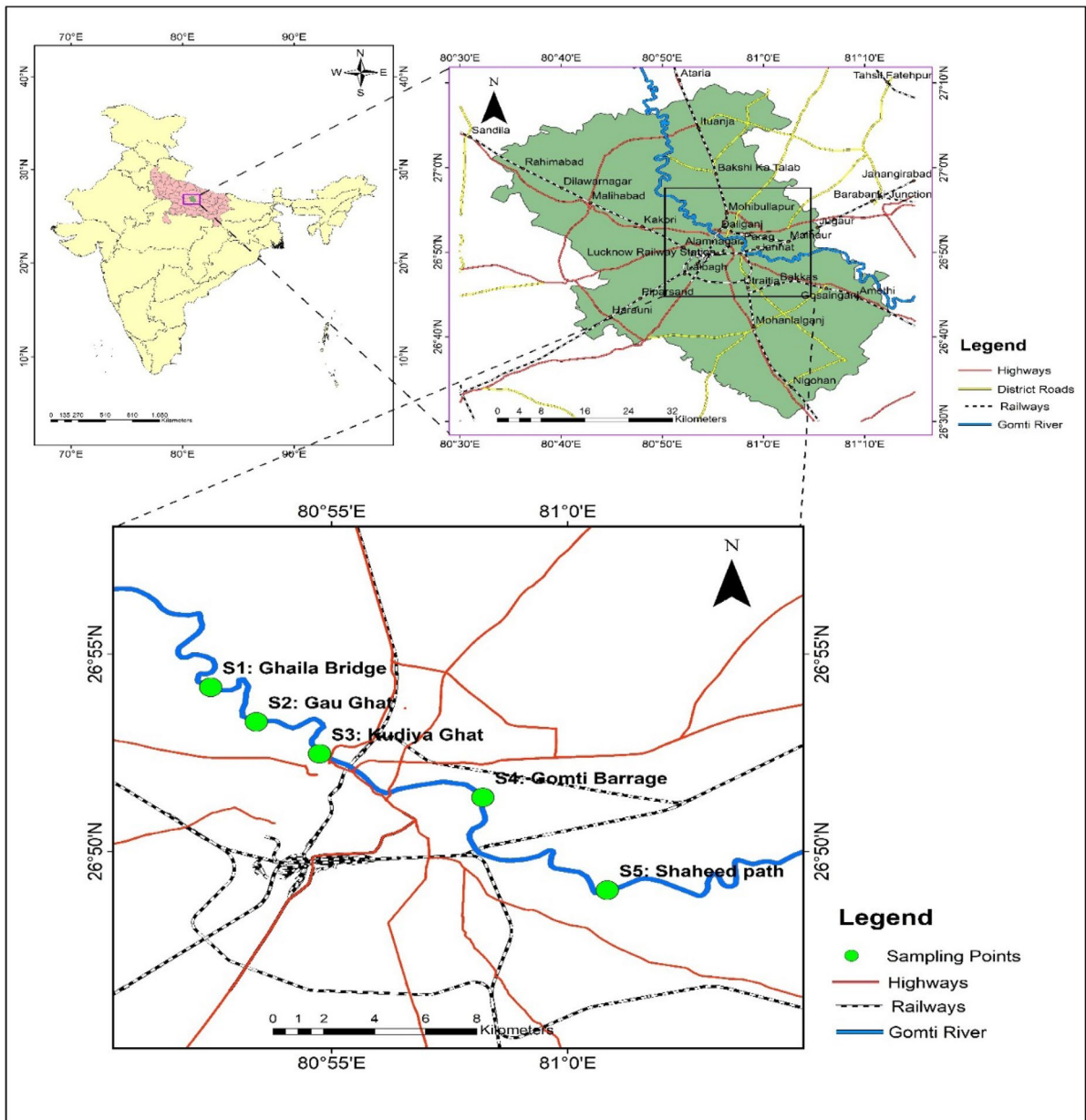


Fig. 1 Study area with the sampling locations (S1 to S5) for the river Gomti in Lucknow

Estimation of WQI

Water quality index (WQI) for all 5 sampling locations during pre-monsoon and post-monsoon seasons were estimated using 12 key physicochemical parameters namely pH, BOD, conductivity, nitrate, TDS, total alkalinity, total hardness, DO, TSS, COD, sulfate, and chloride. The most recommended WQI

categorization for the Indian rivers has been applied for the present study and the index classification is presented in Table 1 (Matta et al., 2020; Priya & Vidya, 2019; Bora & Goswami, 2017; Tripathi et al., 2011). Furthermore, the comparison of WQI from different sampling locations is also presented to categorize the prominent polluted spots. WQI used the aggregated quality rating with unit weights to

Table 1 Classification for water quality index (WQI)

Category	Index range	Usability
Very good	0–25	Drinking, irrigation and industrial
Good	26–50	Drinking, irrigation and industrial
Poor	51–75	Irrigation and industrial
Bad	76–100	Irrigation
Worse	> 100	Proper treatment required before use

the total arithmetic weighted average as illustrated below:

$$WQI = \sum Q_n W_n / \sum W_n$$

where,

Q_n = quality rating for the n^{th} water quality parameter expressed as:

$$Q_n = [(V_n - V_{10}) / (S_n - V_{10})] \times 100$$

V_n = estimated value of n^{th} water quality parameters of collected samples,

S_n = standard permissible value of n^{th} water quality parameter,

V_{10} = ideal value of n^{th} water quality parameter in pure water,

(V_{10} value is 0 for all other parameters except for pH, and DO, V_{10} is 7.0 and 14.6 respectively),

n = number of water quality parameters and,

W_n = unit weight for n^{th} water parameter which is inversely proportional to the standard. The permissible value of the n^{th} water quality parameter is expressed as follows:

$$W_n = K / S_n$$

where,

S_n = standard permissible value of n^{th} water parameter,

K = constant of proportionality,

$$K = [1 / (\sum 1/S_n)].$$

Karl Pearson’s correlation analysis

Statistical software IBM® SPSS (version 26.0) was used to evaluate Karl Pearson’s coefficient of correlation for physicochemical parameters of water and river bed-sediment samples. The significance level of $p < 0.05$ and $p < 0.01$ was applied to the

physicochemical parameters, and the maximum reliance associations were determined between the water and bed sediment of the river.

ANOVA analysis

The variations in the water quality from 5 sampling locations were analyzed using the ANOVA test. One-way ANOVA is recommended as a more effective tool than two-way ANOVA for water quality analyses (Pujar et al., 2020). One-way ANOVA was applied to each water and sediment quality parameter, and the peculiarity between the sampling locations was estimated. The degree of variance between the mean values of various parameters was analyzed at a 0.05% level of significance. The test statistics of ANOVA emphasized the dominant site-specific sources along the flow of the river Gomti.

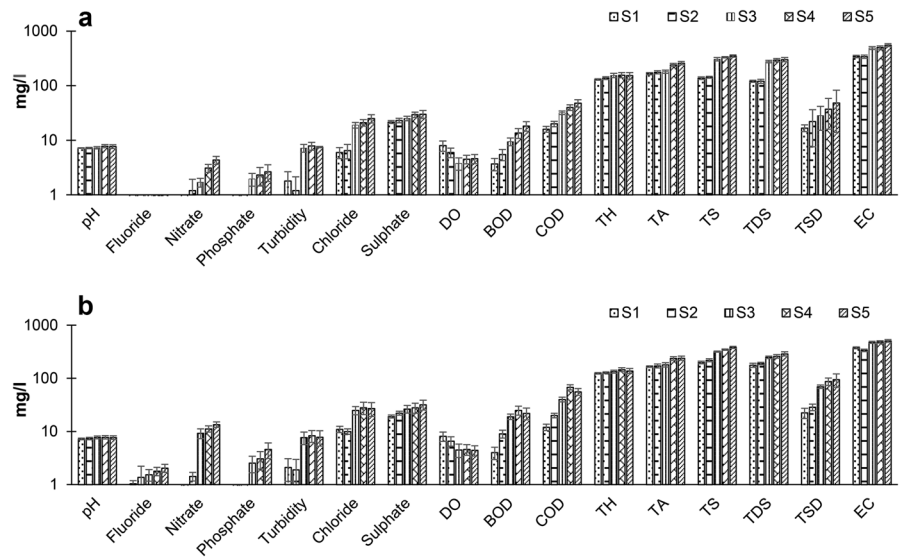
Results and discussion

Physico-chemical analysis for water and bed sediment

Spatial, temporal, and parametric comparisons for the water and bed-sediment samples in Gomti River are presented in Figs. 2 and 3, respectively. Physicochemical analysis results of 16 water and 6 bed-sediment samples have been distributed on a logarithmic scale for easy understanding and interpretation. This river water quality assessment demonstrates that sources other than agri-fields such as effluents emerging from industrial and anthropogenic activities along the route of river flow have contributed to pollution consistently. The magnitude of parametric concentration gradually increased by 5–15% among the sampling locations S1 to S5, i.e., upstream to downstream. The cumulative effects of local factors and flows of urban sewage resulted in an accumulation of organic and inorganic pollutants that impact downstream water quality significantly. Monsoon certainly impacts the drains as well as run-off from neighboring agricultural fields with washout of pesticides from the fields greatly affecting the physicochemical parameters of water samples and bed sediment of Gomti River during the post-monsoon season in comparison to pre-monsoon season.

The pH of Gomti River water during pre-monsoon and post-monsoon ranged between 7.2 ± 0.1 to 7.7 ± 0.60

Fig. 2 Mean values of physico-chemical parameters of Gomti River water at S1, S2, S3, S4, and S5 sampling sites during pre-monsoon **a** and post-monsoon **b** season

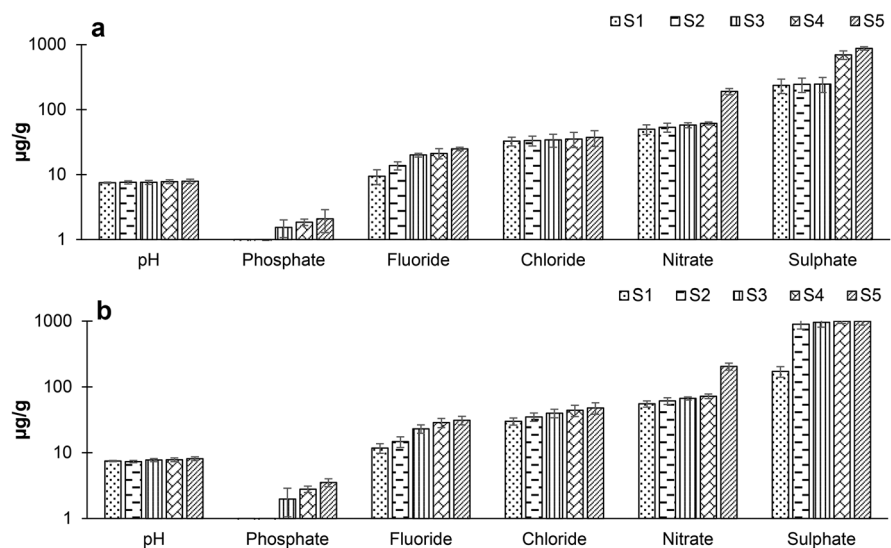


and 7.22 ± 0.28 to 7.69 ± 0.59 while pH of the bed sediment ranged from 7.5 ± 0.17 to 7.9 ± 0.6 and 7.31 ± 0.14 to 8.12 ± 0.54 , respectively. The pH values of river water were within the BIS: 10500 (6.5–8.5) prescribed limit. Turbidity of river water ranged from 1.8 ± 0.85 to 7.5 ± 1.97 NTU (pre-monsoon) and 2.1 ± 0.95 to 7.8 ± 2.52 NTU (post-monsoon). Turbidity is caused by suspended solids, clay, silt, colloidal particles, pollen grain, and microscopic aquatic organisms. The values of turbidity exceeded the BIS standard of 5 NTU at S3, S4, and S5 sampling points. Electric conductivity values ranged between 342 ± 17.08 to

552 ± 36.47 $\mu\text{S/cm}$ (pre-monsoon) and 375 ± 16.09 to 507 ± 27.05 $\mu\text{S/cm}$ (post-monsoon). Pure water has zero conductivity and as contamination increases conductivity also increases. EC values were higher than the (300 $\mu\text{S/cm}$) standard prescribed by the Bureau of Indian Standard (BIS).

Chloride and total dissolved solids (TDS) in the water samples were between 6 ± 1.37 to 25 ± 4.22 mg/l and 199 ± 8.07 to 300.4 ± 26.42 mg/l during pre-monsoon whereas during the post-monsoon period these values were between 11 ± 1.48 to 27 ± 7.85 mg/l and 120.3 ± 5.18 to 289.3 ± 25.41 mg/l, respectively. TDS

Fig. 3 Mean values of physico-chemical parameters of Gomti River bed sediment at S1, S2, S3, S4, and S5 sampling sites during pre-monsoon **a** and post-monsoon **b** season



and chloride values were below the BIS: 10500 limit of 500 mg/l and 250 mg/l, respectively. The chloride concentration in river bed-sediment samples ranged between 32.6 ± 5.01 to 37.2 ± 10.01 $\mu\text{g/g}$ (pre-monsoon) and 30 ± 3.71 to 40 ± 9.64 $\mu\text{g/g}$ (post-monsoon). The concentration of total alkalinity ranged from 166 ± 7.54 to 258 ± 18.37 mg/l (pre-monsoon) and 166 ± 5.77 to 240 ± 21.53 mg/l (post-monsoon) while total hardness was between 130 ± 4.01 to 153 ± 20.87 mg/l (pre-monsoon) and 124 ± 3.54 to 138 ± 14.91 mg/l (post-monsoon), respectively. The total hardness of river water depends on the concentration of Mg^{++} and Ca^{++} ions. Alkalinity values were higher than the prescribed limits (200 mg/l), while the values of total hardness were below the BIS prescribed limit of 200 mg/l.

The dissolved oxygen (DO), a key indicator parameter of water quality ranged from 4.6 ± 0.87 to 8 ± 1.71 mg/l (pre-monsoon) and 4.4 ± 0.97 to 8.1 ± 1.60 mg/l (post-monsoon). The level of DO depends on the temperature, sufficient water flow, solids and microbial processes in the river water (Tian et al., 2019). Sudden discharge of untreated effluent with high BOD load suddenly depletes the DO. All the water bodies must have 4–6 mg/l of DO to maintain aquatic life forms (Shivayogimath et al., 2012). Two instances of large-scale fish mortality were reported from the stretch of the river under study, and the same was attributed to waste discharge from a brewery industry which was subsequently closed. The concentration of biochemical oxygen demand (BOD_5) and chemical oxygen demand (COD) ranged from 3.7 ± 0.93 to 18.3 ± 3.65 mg/l and 16 ± 1.97 to 48 ± 7.41 mg/l during the pre-monsoon period and between 4 ± 1.05 and 25 ± 4.76 mg/l and 12 ± 1.66 and 56 ± 8.07 mg/l during the post-monsoon period, respectively. As the Gomti River receives sewage from different drains at different points, the value of BOD_5 increased from upstream to downstream sampling sites. The high values of BOD, greatly exceeding the desirable level, are due to the contamination by organic and domestic sewage. COD indicates both organic as well as inorganic pollutants present in river water, and the levels were within the standard limits.

The nitrate and phosphate in water samples ranged from 0.4 ± 0.26 to 1.7 ± 1.19 mg/l and 0.4 ± 0.26 to 3 ± 1.67 mg/l during pre-monsoon but 0.66 ± 0.26 to 5.32 ± 0.95 mg/l and 0.34 ± 0.27 to 2.22 ± 1.31 mg/l during post-monsoon, respectively. The nitrate and phosphate in bed-sediment samples ranged between

49.83 ± 8.43 to 129.59 ± 45.62 $\mu\text{g/g}$ and 0.46 ± 0.13 to 2.08 ± 1.24 $\mu\text{g/g}$ during pre-monsoon but 55.92 ± 6.95 to 197.73 ± 35.09 $\mu\text{g/g}$ and 0.4 ± 0.24 to 2.2 ± 1.56 $\mu\text{g/g}$ during post-monsoon, respectively. Direct discharge of raw municipal sewage may be the primary cause of nitrate and phosphate pollution of Gomti River water. Researchers at different time points also reported that sewage with high organic matter is the main source of nitrate and phosphate pollution (Singh et al., 2016). In addition, phosphates and nitrates could also be a part of industrial wastes, detergents, fertilizers, and agricultural chemicals draining into the river system. Some nitrogen-fixing organisms are also the source of nitrate pollution in river water. High values of the nitrate were found post-monsoon at sampling sites S3, S4, and S5. Excess amounts of nitrate in drinking water may cause methemoglobinemia, a childhood disease. Once phosphates and nitrates enter the aquatic ecosystem, these pollutants support and lead to the luxurious growth of algae, water hyacinth (*Eichhornia crassipes*), and other aquatic weeds in the river system. They generate a foul odor and result in the death of algae due to the unavailability of sufficient dissolved oxygen leading to eutrophication (Rolle et al., 2019). Eutrophication disturbs the whole carbon cycle among aquatic organisms, from prokaryotes to zooplankton (Lopez et al., 2019).

The fluoride and sulfate ranged from 0.3 ± 0.18 to 0.6 ± 0.39 mg/l and 21.6 ± 1.31 to 30.1 ± 5.04 mg/l during pre-monsoon while 1.5 ± 1.06 to 1.97 ± 1.04 mg/l and 19.1 ± 1.21 to 31.9 ± 6.72 mg/l during post-monsoon, respectively in water samples. However, in bed sediment, the fluoride and sulfate concentration ranged between 18.12 ± 4.30 to 22.57 ± 1.26 $\mu\text{g/g}$ and 244 ± 61.31 to 774 ± 123.88 $\mu\text{g/g}$ during pre-monsoon while 21.75 ± 9.89 to 30.34 ± 7.71 $\mu\text{g/g}$ and 172 ± 32.04 to 1094 ± 219.43 $\mu\text{g/g}$ during post-monsoon, respectively. Though fluoride concentration is slightly above the prescribed limit for drinking water of 1.5 mg/l (BIS: 10500, 2012); however, chronic exposure and illness due to low-level fluoride cannot be ruled out. Fluoride-related illnesses are dental, skeletal, mottled enamel, osteosclerosis, and non-skeletal fluorosis disorder (Sahu et al., 2018). Mainly fluoride, nitrate, phosphate, chloride, and sulfate, in bed sediment samples are significantly high. However, the concentrations of physicochemical parameters in both bed sediment and water samples show a wide variation between pre-monsoon and post-monsoon seasons.

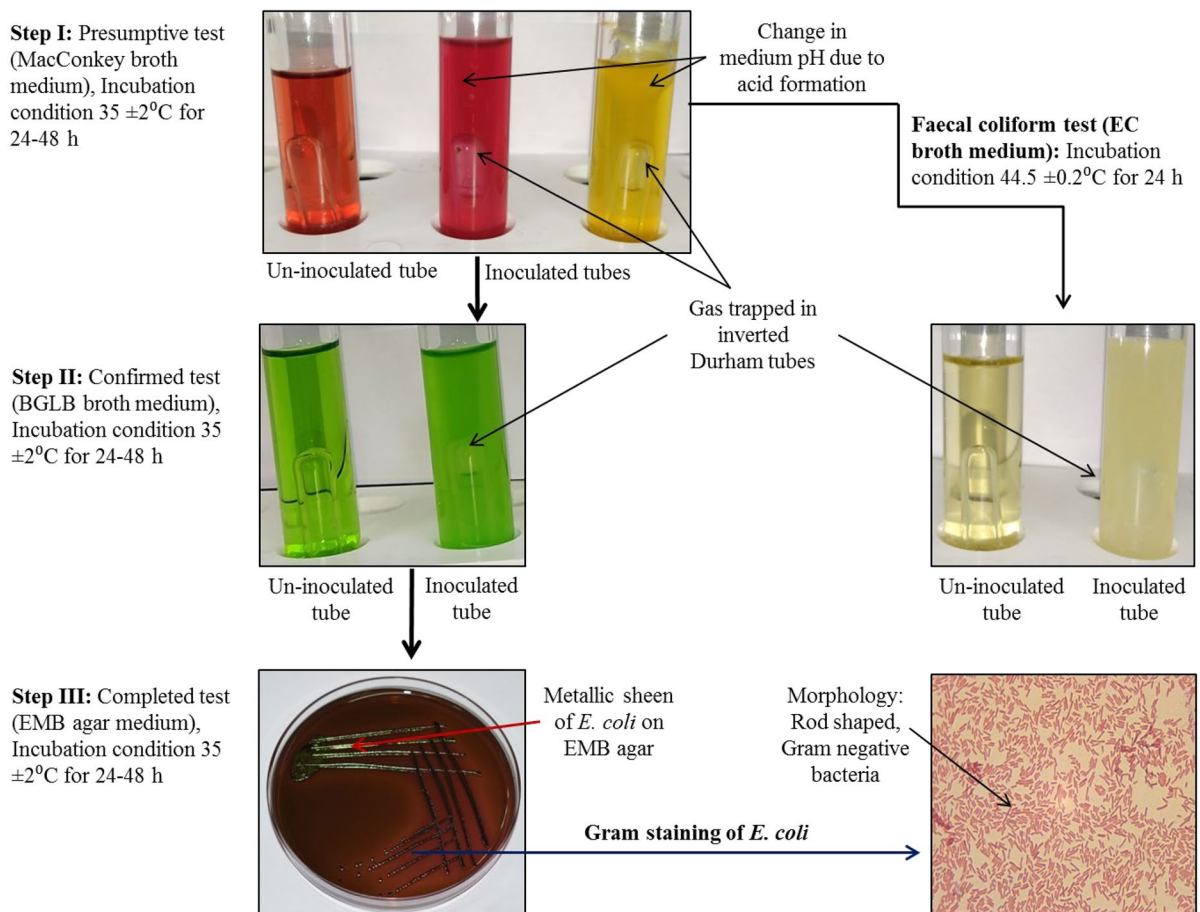
Table 2 Enumeration of total coliform and fecal coliform as MPN index/100 ml

Sampling location	Pre-monsoon		Post-monsoon	
	Total coliform	Fecal coliform	Total coliform	Fecal coliform
S1	280	Present	350	Present
S2	350	Present	430	Present
S3	1600	Present	1600	Present
S4	1600	Present	>1600	Present
S5	>1600	Present	>1600	Present

Bacteriological analysis

Bacteriological examination results for the identification of *Escherichia coli* and fecal coliform are presented in Table 2 and Fig. 4. The enumeration results showed that the total coliform count levels were higher than their prescribed numbers at all the locations. The MPN (most probable number) index

of coliforms was found to be higher than the recommended level of no-coliform/100 ml (BIS: 10500, 2012) during both the seasons of water sampling. Gas production in the EC broth was an indication of the occurrence of thermo-tolerant fecal coliform while the development of metallic sheen colonies on agar plates confirmed the presence of *E. coli* in all the water samples. Rod-shaped gram-negative

**Fig. 4** Test for identification of *E. coli* and fecal coliform

bacteria were observed under a light microscope (Leica DM-1000, Germany), the presence of which confirms that Gomti River water is contaminated with pathogenic bacteria.

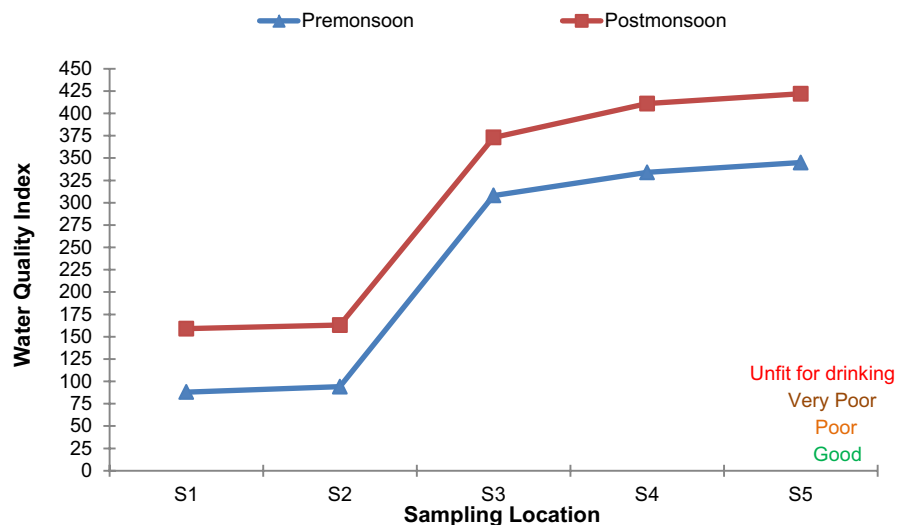
MPN count was found to be higher during the post-monsoon sampling compared to the pre-monsoon period. The material cycling of pollutants may be triggered during summer due to high temperature and excessive microbial activities resulting in a reduction of nutrients in the rivers (Bao et al., 2015; Islam et al., 2018). Similar findings were also reported from studies on water pollution of Gomti River at Jaunpur (Singh & Singh, 2014), Barak river at Assam (RajKumar & Sharma, 2013) and Gola river at Uttarakhand (Chandra et al., 2006) in India. Furthermore, the MPN counts of the total coliform and fecal coliform gradually increased from upstream sites (S1), receiving a lesser amount of municipal sewage, compared to downstream (S5) sites, which receive a huge amount of municipal sewage through 26 drains. Hence, it is opined that excess bacterial contamination happened due to open defecation as well as discharge of untreated sewage in the downstream region of the Gomti River. The occurrence of *E. coli* indicates that river water is polluted by pathogenic micro-organisms while fecal coliform is attributed to the open defecation and discharge of untreated domestic sewage along the banks of the river. Literature survey confirmed different strains of fecal coliform and *E. coli* detected in the digestive systems which cause stomach diseases, viz., diarrhea (Haque et al., 2019; Melliawati, 2009).

Estimation of WQI

The WQI was estimated for 5 water sampling locations using 12-physicochemical parameters. WQI comparisons among sampling locations and between the 2 seasons are presented in Fig. 5. WQI for post-monsoon season was significantly higher than the pre-monsoon at all 5 sampling locations. The WQI values ranged from 88 to 345 during pre-monsoon season and from 159 to 422 during post-monsoon season. The WQI indicated “very poor” status at S1 and S2 sampling sites during pre-monsoon season and the “worse” status for all remaining sampling sites during both seasons. In both seasons, a gradual increase of WQI was found from S1 to S5 sampling locations which specifies the degree of water quality deterioration of Gomti River downstream. A significant change in WQI value from S2 to S3 site was observed because of many additional sewage discharging drains merging with the river.

The results from the WQI analyses, spatial and seasonal assessment of respective physicochemical parameters were validated with similar findings reported in the literature. The WQI of the present study is compared with other studies having similar procedures and WQI results which are indicative of a similar seasonal pattern. Several studies also reported higher WQI values during post-monsoon seasons as compared to pre-monsoon periods for various rivers. Figure 6 shows the comparisons of the seasonal WQI between the Gomti River from the

Fig. 5 Comparison between seasonal and spatial variations of WQI for Gomti River



present study and the WQI of other rivers in India (Gupta et al., 2017; Kumar & Bahadur, 2013; Rizvi et al., 2016; Shah & Joshi, 2017; Kumar & Dua, 2009; Srivastava et al., 2015). A significant deviation in WQI was observed between the seasons in the current study while in other reported studies the deviation in WQI between the two seasons was found to be almost negligible.

FTIR analysis for river bed-sediment samples

The FTIR analysis was carried out to identify functional groups in the spectral range from 4000 to 500 cm^{-1} for the river bed sediment. The details of FTIR spectral peaks that are related to radical stretches and functional groups are shown in Table 3. Several spectra and their relative peaks of FTIR were found to gradually increase in samples from upstream (S1) to downstream (S5) locations (Fig. 7). Organic pollution-related functional groups, viz., organo-phosphorus compounds, amines, aromatic amines, alcohols, and phenols were found to be predominant compared to other functional groups. The composition of the river bed sediment is grossly affected by organic and inorganic contaminants, and it becomes a pool of toxic pollutants, that persist for a long period of time. These toxic contaminants, viz., pesticides, heavy metals, lauryl alkyl sulfonates

(residues of detergents), polyaromatic hydrocarbons (PAHs), etc., pass into the aquatic life forms through the food chain, especially during the summer when the ambient temperature (35–46 °C) is high, and water flow is reduced to minimal. The water temperature also proportionately increases, and the rate of reaction increases as per Arrhenius theory. As a result, pollutants from sediments are released back into the water in a sustained manner. The results of FTIR analysis for the sediment samples supported the inference drawn based on physicochemical analyses for identifying potential contaminating sources which significantly contribute and impact the river water quality.

Pearson's correction analysis

Strong positive correlations ($p \geq 0.9$) were found among the water quality parameters such as pH, chloride, phosphate, sulfate, turbidity, conductivity, TS, TDS, BOD, and COD for the water samples collected during pre-monsoon and post-monsoon seasons in Tables 4 and 5, respectively. In particular, a significant association of COD with chloride, nitrate, phosphate, sulfate, and total alkalinity reveals high pesticide contamination in the river water. The strong relation of pH with chloride, phosphate, nitrate, and turbidity, TSS, TDS, BOD, and

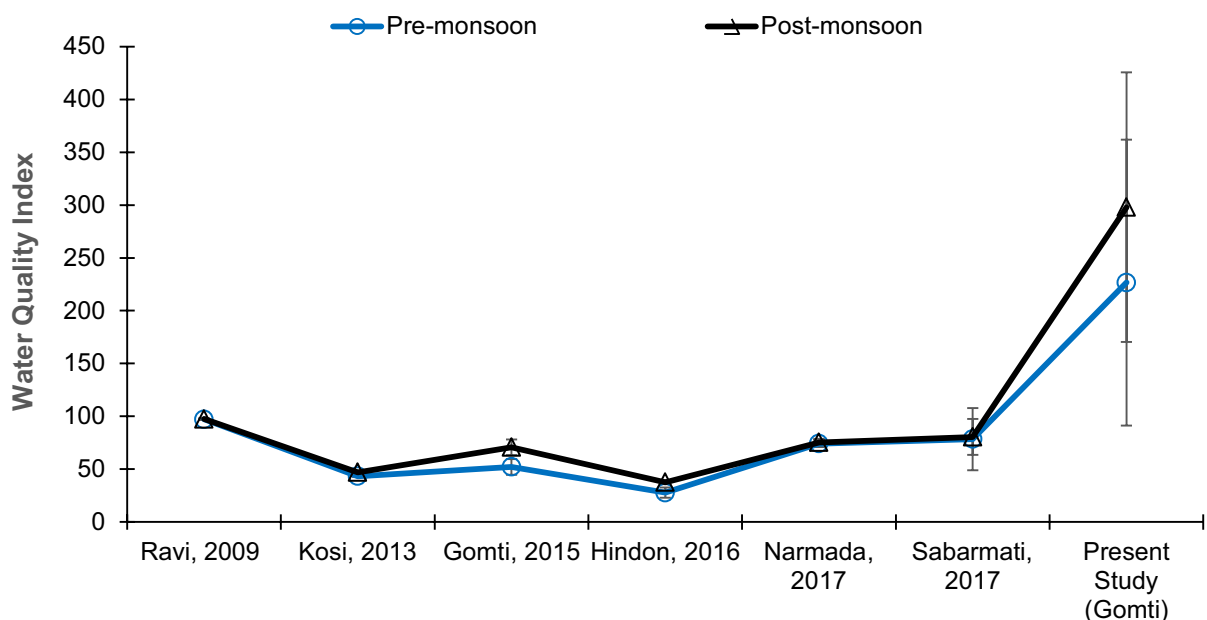


Fig. 6 Seasonal WQI comparison between current and earlier studies

Table 3 Details of FTIR spectral with corresponding radical stretches and functional groups

Spectral peak (cm ⁻¹)	Radical stretching	Functional groups
3625.14	O–H, free hydroxyl	Alcohols and phenols
3359.87	N–H	Amines and amides
3152.21	NH ₃	NH ₃ ⁺ in amino acids
2980.04 and 2936.27	Both –CH ₃ and –CH ₂ –	Aliphatic compounds
2843.60	–CH ₃	Oxygen or Nitrogen
2527.18 and 2520.36	NH ₂	Amines
2159.24	–C=C–	Alkynes
1696.66	C=O, carboxylic acid	Aromatic amides or amines
1471.19	C–C (in-ring)	Aromatics
1454.16	C–H (in bend)	Alkanes
1318.90	N–O (in symmetric)	Nitro compounds
1050.11	SO ₃ H	Sulfonic acids
1032.89 and 1013.42	P–O–C	Organophosphorus compounds
686.60	C–C–CHO (in bending)	Aldehydes

COD indicates that the river is significantly contaminated with industrial effluents.

Furthermore, the prominent association of phosphate with chloride, sulfate, conductivity, and COD indicates that water quality is affected by surfactants. Similarly, the strong correlation of TDS with turbidity, conductivity, TS, BOD, and COD indicates the impact of domestic sewage on Gomti River. However, the level of significant association among the physicochemical parameters was more pronounced during the post-monsoon season compared to pre-monsoon

period since effluents from industrial point sources and non-point agriculture run-off are added to the river. The overall statistical correlations of water samples between the physicochemical parameters indicate that the behavior of polluting sources and their dissipation is analogous at all 5 water sampling locations. The positive correlations among the physicochemical parameters of bed-sediment samples collected in both seasons are presented in Tables 6 and 7, respectively. A significant association was found between phosphate and nitrate with pH in sediment samples which

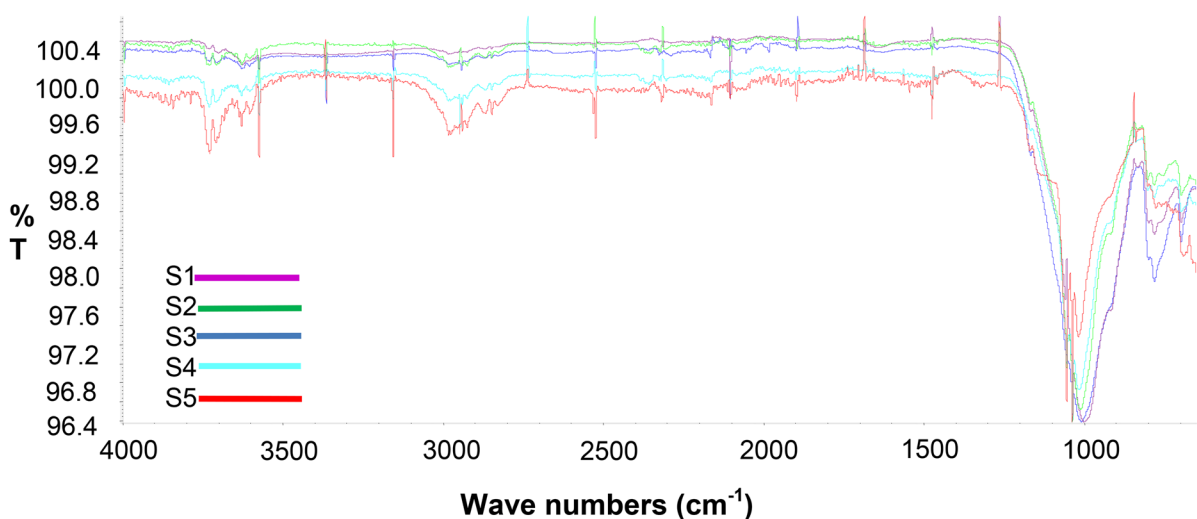


Fig. 7 ATR-FTIR spectra of bed sediment of Gomti River

Table 4 Pearson correlations among the physico-chemical parameters of river water samples for pre-monsoon season

Pearson correlation	pH	Chloride	Nitrate	Phosphate	Sulfate	Fluoride	Turbidity	Cond	TS	TDS	TSS	DO	BOD	COD	TA	TH
pH	1	0.836	0.35	0.769	0.960**	0.412	0.801	0.815	0.825	0.85	0.59	-0.56	0.891*	0.892*	0.957*	0.756
Chloride		1	0.725	0.992**	0.933*	0.841	0.967**	0.999**	0.995*	0.993**	0.845	-0.83	0.949*	0.977*	0.849	0.928*
Nitrate			1	0.794	0.595	0.849	0.648	0.728	0.773	0.692	0.89*	-0.892*	0.671	0.7	0.466	0.78
Phosphate				1	0.898*	0.896*	0.948*	0.994**	0.991**	0.976**	0.89*	-0.853	0.936*	0.963**	0.806	0.921*
Sulfate					1	0.613	0.87	0.917*	0.934*	0.930*	0.786	-0.726	0.973**	0.978**	0.969**	0.863
Fluoride						1	0.802	0.862	0.838	0.806	0.85	-0.787	0.724	0.759	0.496	0.766
Turbidity							1	0.967**	0.962**	0.987**	0.702	-0.845	0.85	0.903*	0.745	0.950*
Conductivity								1	0.991**	0.989**	0.848	-0.823	0.942*	0.970**	0.832	0.919*
TS									1	0.991**	0.859	-0.876	0.943*	0.974**	0.838	0.954*
TDS										1	0.785	-0.848	0.921*	0.959*	0.829	0.853*
TSS											1	-0.752	0.887*	0.877	0.749	0.743
DO												1	-0.708	-0.771	-0.547	-0.958
BOD													1	0.993**	0.957*	0.825
COD														1	0.935*	0.882*
TA															1	713
TH																1

*Correlation is significant at the 0.05 level (2-tailed)

**Correlation is significant at the 0.01 level (2-tailed)

Table 5 Pearson correlations among the physico-chemical parameters of river water samples for post-monsoon season

Pearson Cor- relation	pH	Chloride	Nitrate	Phosphate	Sulfate	Fluoride	Turbidity	Cond	TS	TDS	TSS	DO	BOD	COD	TA	TH
pH	1	0.964**	0.921*	0.974**	0.889*	-0.90*	0.975**	0.908*	0.976**	0.957*	0.973**	-0.984**	0.972**	0.906*	0.729	0.876
Chloride		1	0.896*	0.986**	0.901*	-0.838	0.997**	0.980**	0.989**	0.985**	0.957*	-0.924*	0.964**	0.937*	0.818	0.892*
Nitrate			1	0.85	0.667	-0.825	0.915*	0.814	0.884*	0.829	0.953*	-0.844	0.891*	0.849	0.602	0.869
Phosphate				1	0.943*	-0.876	0.987**	0.972**	0.995**	0.998**	0.949*	-0.96**	0.957*	0.907*	0.794	0.847
Sulfate					1	-0.722	0.885*	0.891*	0.904*	0.942*	0.796	-0.926*	0.918*	0.887*	0.875	0.811
Fluoride						1	-0.873	-0.823	-0.904*	-0.866	-0.939*	0.878	-0.774	-0.643	-0.404	-0.591
Turbidity							1	0.973**	0.994**	0.983**	0.975**	-0.934*	0.960**	0.920*	0.776	0.878
Conductivity								1	0.974**	0.983**	0.918*	-0.867	0.899*	0.875	0.794	0.803
TS									1	0.993**	0.973**	-0.948*	0.946*	0.890*	0.749	0.835
TDS										1	0.938*	-0.941*	0.942*	0.896*	0.797	0.828
TSS											1	-0.923*	0.915*	0.843	0.628	0.815
DO												1	-0.958	-0.881	-0.73	-0.842
BOD													1	0.978**	0.859	0.957*
COD														1	0.929*	0.987**
TA															1	0.891*
TH																1

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

Table 6 Pearson correlations among the physico-chemical parameters of river bed-sediment samples for pre-monsoon season

Pearson correlation	pH	Chloride	Nitrate	Phosphate	Sulfate	Fluoride
pH	1	0.533	0.741	0.443	0.837	-0.699
Chloride		1	0.444	-0.028	0.362	-0.145
Nitrate			1	0.628	0.951*	-0.622
Phosphate				1	0.508	-0.921*
Sulfate					1	-0.579
Fluoride						1

*Correlation is significant at the 0.05 level (2-tailed)

Table 7 Pearson correlations among the physico-chemical parameters of river bed-sediment samples for post-monsoon season

Pearson correlation	pH	Chloride	Nitrate	Phosphate	Sulfate	Fluoride
pH	1	0.578	0.742	0.943*	0.432	-0.429
Chloride		1	0.377	0.336	-0.106	-0.603
Nitrate			1	0.611	0.505	-0.503
Phosphate				1	0.585	-0.143
Sulfate					1	0.476
Fluoride						1

*Correlation is significant at the 0.05 level (2-tailed)

indicates the dominance of surfactants, fertilizers, and pesticides as contaminating sources of river pollution.

ANOVA test

The ANOVA results for the water and bed-sediment samples for all 5 locations are shown in Table 8. F-statistic of ANOVA test at $p \leq 0.05$ of the water quality parameters showed that the TDS, TSS, and hardness of water samples had a significant variation compared to the other parameters. The excess value of F-statistics for TDS, TSS, and hardness parameters indicated that extraneous source-induced contamination is substantial from upstream to downstream of Gomti River. Furthermore, a significant variation was also found in the fluoride and nitrate levels among water quality parameters at $p \leq 0.05$. This condition specifies the impact of pesticide contamination at different sampling locations along the river stretch. However, a statistically insignificant variation from the ANOVA test ($p > 0.05$) was found in the sediment quality parameters from 5 sampling locations other than fluoride ($F = 5.67$; $p < 0.05$) contamination. One-way ANOVA F-statistics value ($p \geq 0.05$) for parameters of water quality revealed significant variation between sampling locations indicating sources of contamination, whereas for parameters of sediment quality ANOVA test provided insignificant spatial variations.

Table 8 ANOVA test statistics on water and bed-sediment quality parameters of sampling locations

Parameters	F-statistic	P values
Water samples		
pH	0.395	0.547
Chloride	0.709	0.424
Nitrate	4.097	0.078
Phosphate	0.214	0.656
Sulfate	0.018	0.896
Fluoride	144.838	0
Turbidity	0.045	0.838
Conductivity	0.023	0.882
Total solids	0	0.989
TDS	25.434	0.001
TSS	4.386	0.07
DO	0.061	0.811
BOD	1.4	0.271
COD	0.436	0.528
Total alkalinity	0.037	0.852
Total hardness	3.592	0.095
Bed-sediment samples		
pH	0.002	0.964
Chloride	0.04	0.846
Nitrate	0.001	0.972
Phosphate	0.195	0.671
Sulfate	0.173	0.689
Fluoride	5.672	0.044

Conclusion

The present study revealed that the post-monsoon water quality parameters of Gomti River are significantly higher than the pre-monsoon period. The study also helps in identifying the dominant or fugitive contamination sources along the riverbank. The biological and physicochemical properties of water have changed due to the mixing of raw/semi-treated urban sewage, open defecation, agricultural surface run-offs, industrial effluents, and several other hundreds of fugitive pollution sources. BOD, COD, nitrate, phosphates, pesticides, and MPN index of *E. coli*, and fecal coliform were relatively higher during the post-monsoon period when compared to pre-monsoon. The values of WQIs indicated the intensity of damage and deterioration of water quality from upstream to downstream sampling sites. The river stretch contaminated with organic pollution attributed to sewage was confirmed with the identification of different functional groups of organic and inorganic compounds by FTIR. Furthermore, the multivariate statistical analysis has validated the assessment of bed sediment, and water quality for seasonal effects and spatial comparisons. The significant correlations between the specified parameters showed that dominant sources were surfactants and pesticides. Also, the F-statistics of ANOVA ascertained the significant variation between sites for contaminants and a justified load of pollution by agrochemicals as well as urban sewage run-off. The results support cutting down the sources of the contaminants that drain into the Gomti and developing remediation strategies to abate the river pollution. Every housing society should have its primary sewage treatment plant and solid waste dumping yards. Grid base inventory for every segment of river stretch from origin to confluence could be advantageous in reducing the pollution load.

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Author contribution All the authors have substantially and significantly contributed to this manuscript. G. C. Kisku has planned/designed the study and finalized this manuscript for submission. A. Kumar collected and analyzed water and sediment samples and wrote this manuscript. B. Sreekanth conducted a statistical analysis of data for correlation analysis, calculated the WQI and proofread of manuscript. A. Maurya established the microbiological examination of water samples.

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Declarations

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